Inhomogeneous cloud parameters retrieval from multispectral and multiscale information by using neural network: Test with MODIS data

C. Cornet[1,2,]

J.C. Buriez[1,] J. Riédi[1], H. Isaka[2], B. Guillemet[2]

(1) Laboratoire d'Optique Atmosphérique (LOA)
Université des sciences et Technologies de Lille, France

(2) Laboratoire de Météorologie Physique (LAMP),
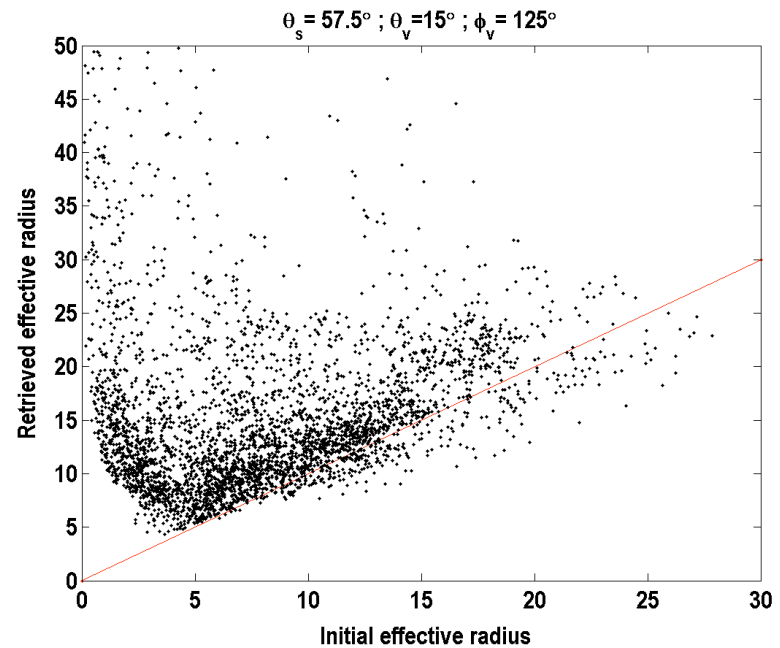Université Blaise Pascal, Clermont-Ferrand, France

Homogeneous cloud assumption

• Usual cloud parameter retrieval = homogeneous clouds assumption

⇒ Errors on retrieval parameter due to cloud inhomogeneity:
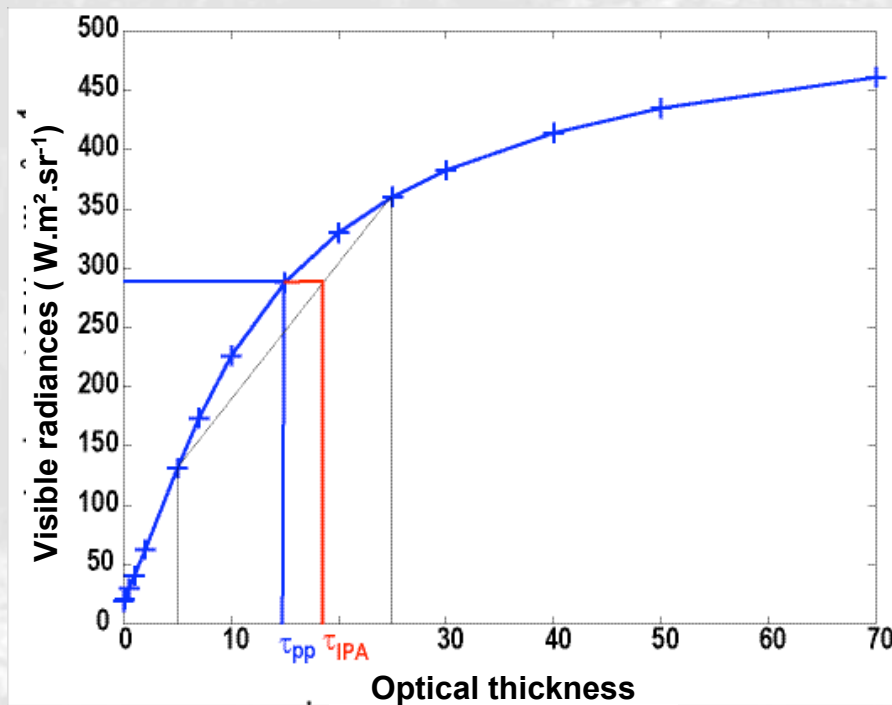
Optical thickness
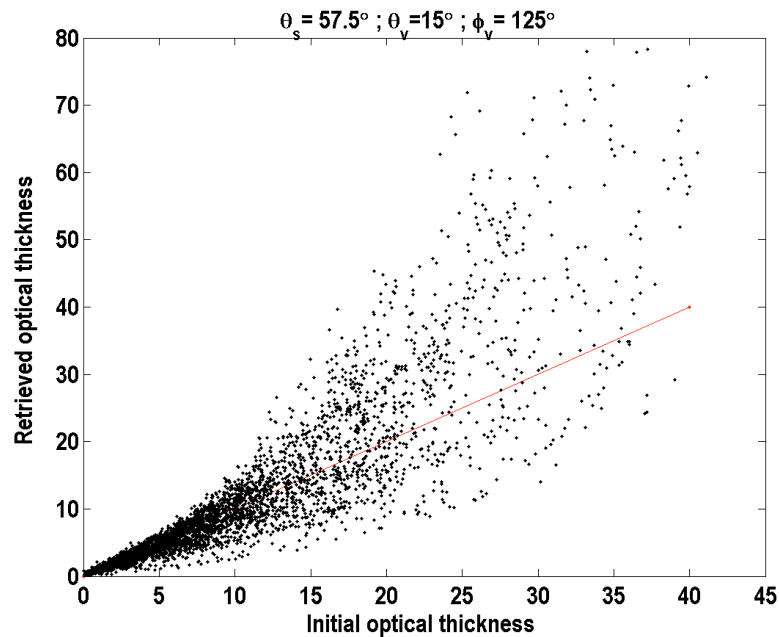
Effective radius

Errors due to the cloud heterogeneity

• nonlinearity effect of radiance as a function of optical thickness

"*Plane-parallel bias*" (*Cahalan et al., 1994; Loeb et al., 1997, Szczap et al., 2000*)

$\tau_{true} \neq \tau_{IPA}$

because of neighboring pixels

• Radiative smoothing

• Shadowing and brightness effects

(Marshak et al.,1995; Davis et al., 1997;
Loeb et al., 1998; Oreopoulos et al., 2000;
Varnai et al. 2000; Varnai et Marshak, 2002)

• Improvements of observational capabilities

GLI (2002); MERIS (2002); MISR (2000); MODIS (2000; 2002); POLDER (1997; 2002) ....

Heterogeneous cloud model

A 1kmx1km:
- ✓ Mean optical thickness
- ✓ Mean effective radius
- ✓ Cloud top temperature

- ✓ Sub-pixel fractional cloud cover
- ✓ Optical thickness heterogeneity
- ✓ Effective radius heterogeneity

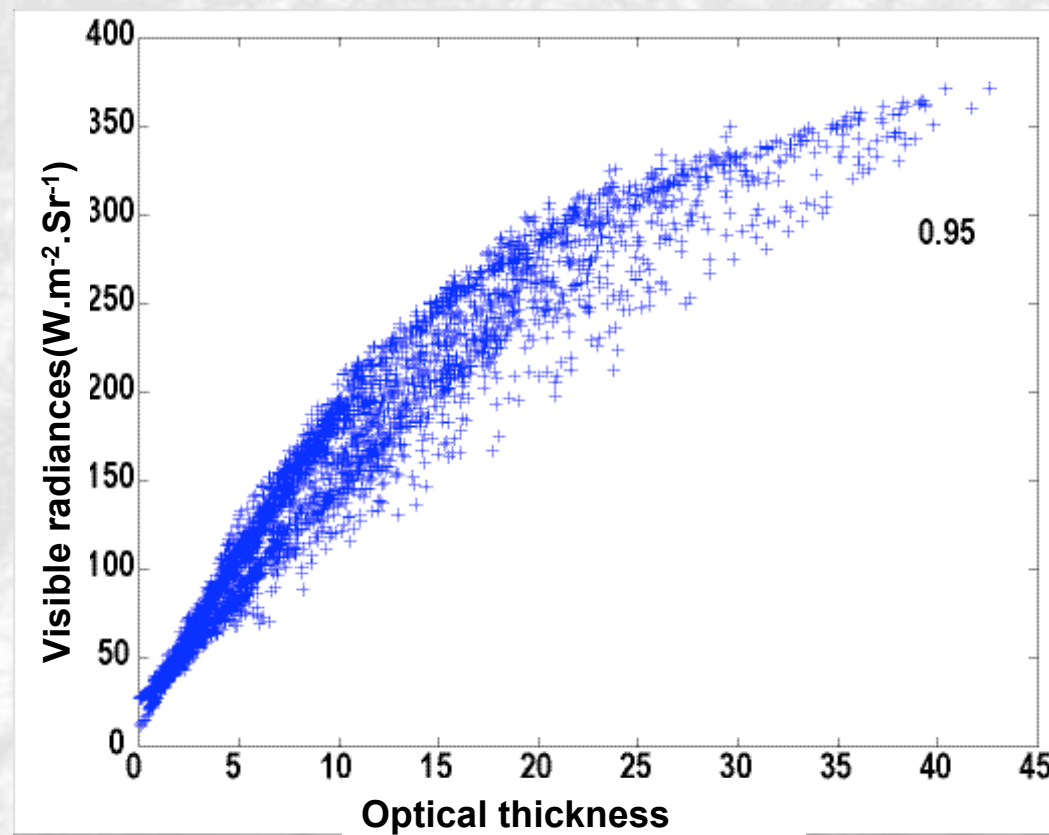# Multispectral information (MODIS, GLI)

Visible radiances 0.865μm

$1km^2$ + $250\times250m^2$

A 1kmx1km:
- ✓ Mean optical thickness
- ✓ Mean effective radius
- ✓ Cloud top temperature

- ✓ Sub-pixel fractional cloud cover
- ✓ Optical thickness heterogeneity
- ✓ Effective radius heterogeneity

Multispectral information (MODIS, GLI)

Relation between visible radiances and optical thickness

Multispectral information (MODIS, GLI)

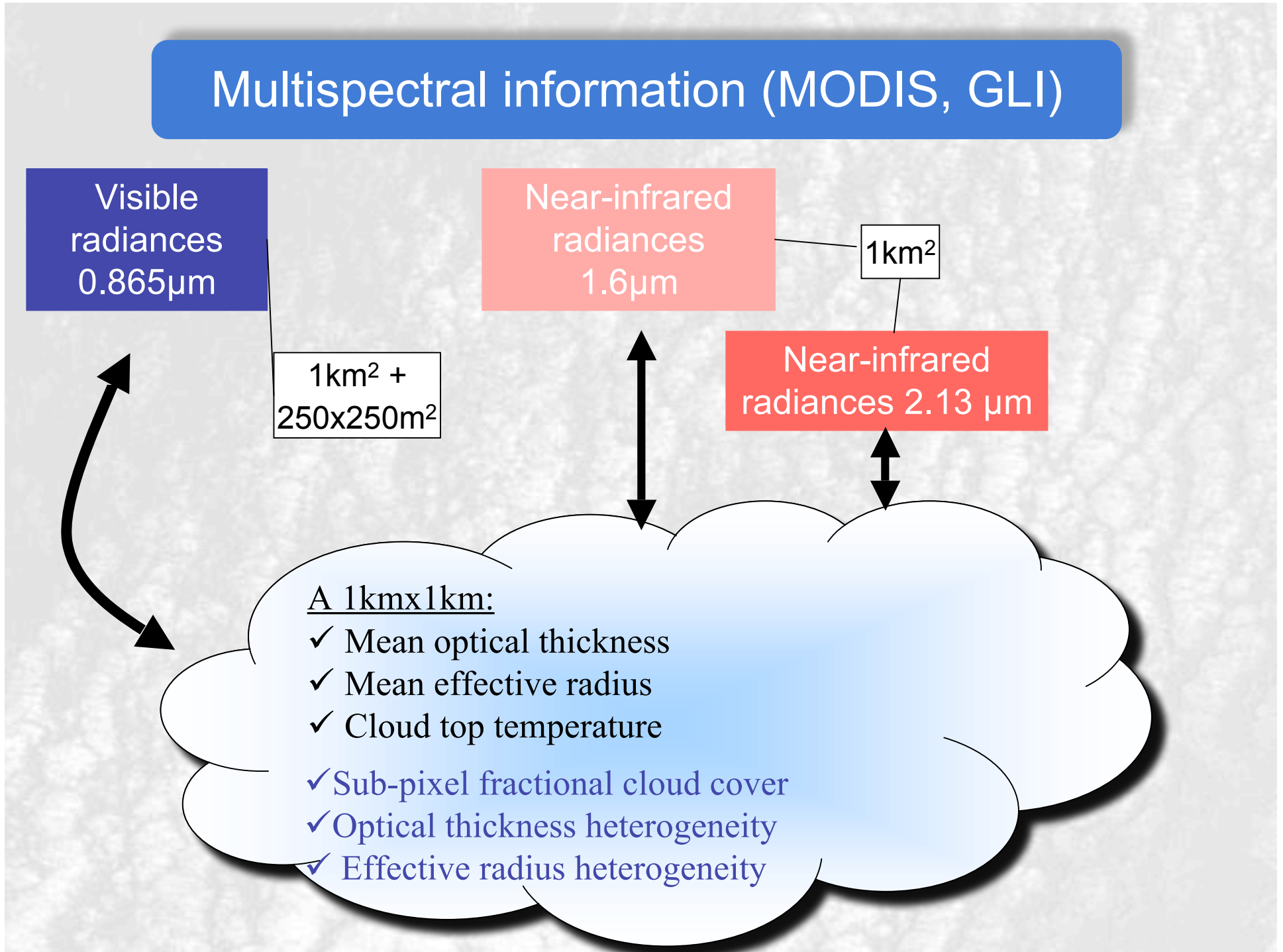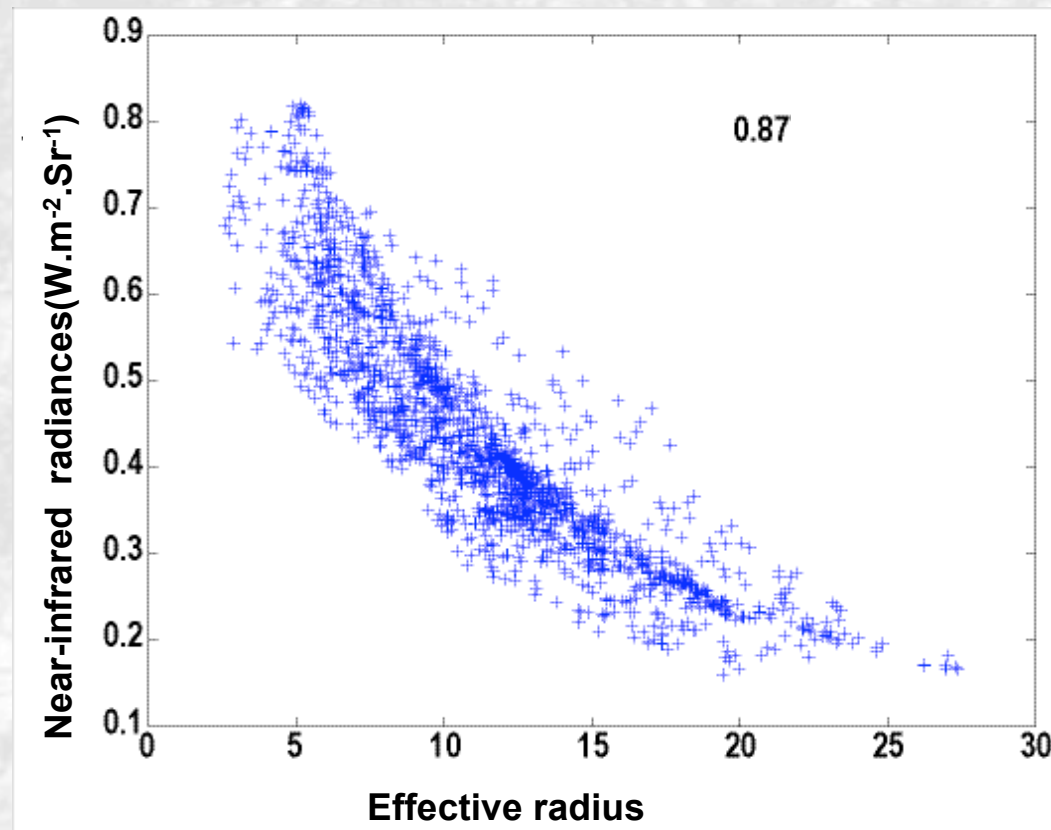Visible radiances 0.865μm

Near-infrared radiances 1.6μm

$1km^2$

$1km^2 +$
$250 \times 250m^2$

Near-infrared radiances 2.13 μm

A 1kmx1km:
- Mean optical thickness
- Mean effective radius
- Cloud top temperature

- Sub-pixel fractional cloud cover
- Optical thickness heterogeneity
- Effective radius heterogeneity

Multispectral information (MODIS, GLI)

Relation between near-infrared radiances and effective radius
(*cf* >0.8)

Multispectral information (MODIS, GLI)

Visible radiances 0.865μm

Near-infrared radiances 1.6μm

1km²

Infrared radiances 11μm

1km² + 250x250m²

Near-infrared radiances 2.13 μm

A 1kmx1km:
- ✓ Mean optical thickness
- ✓ Mean effective radius
- ✓ Cloud top temperature

- ✓ Sub-pixel fractional cloud cover
- ✓ Optical thickness heterogeneity
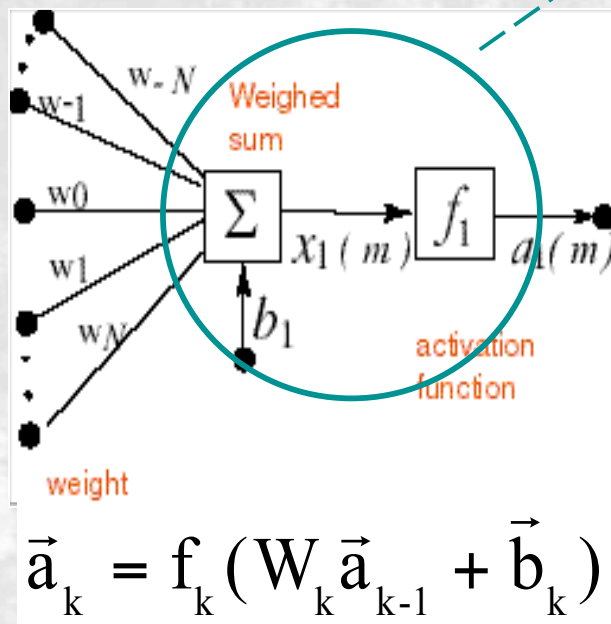- ✓ Effective radius heterogeneity
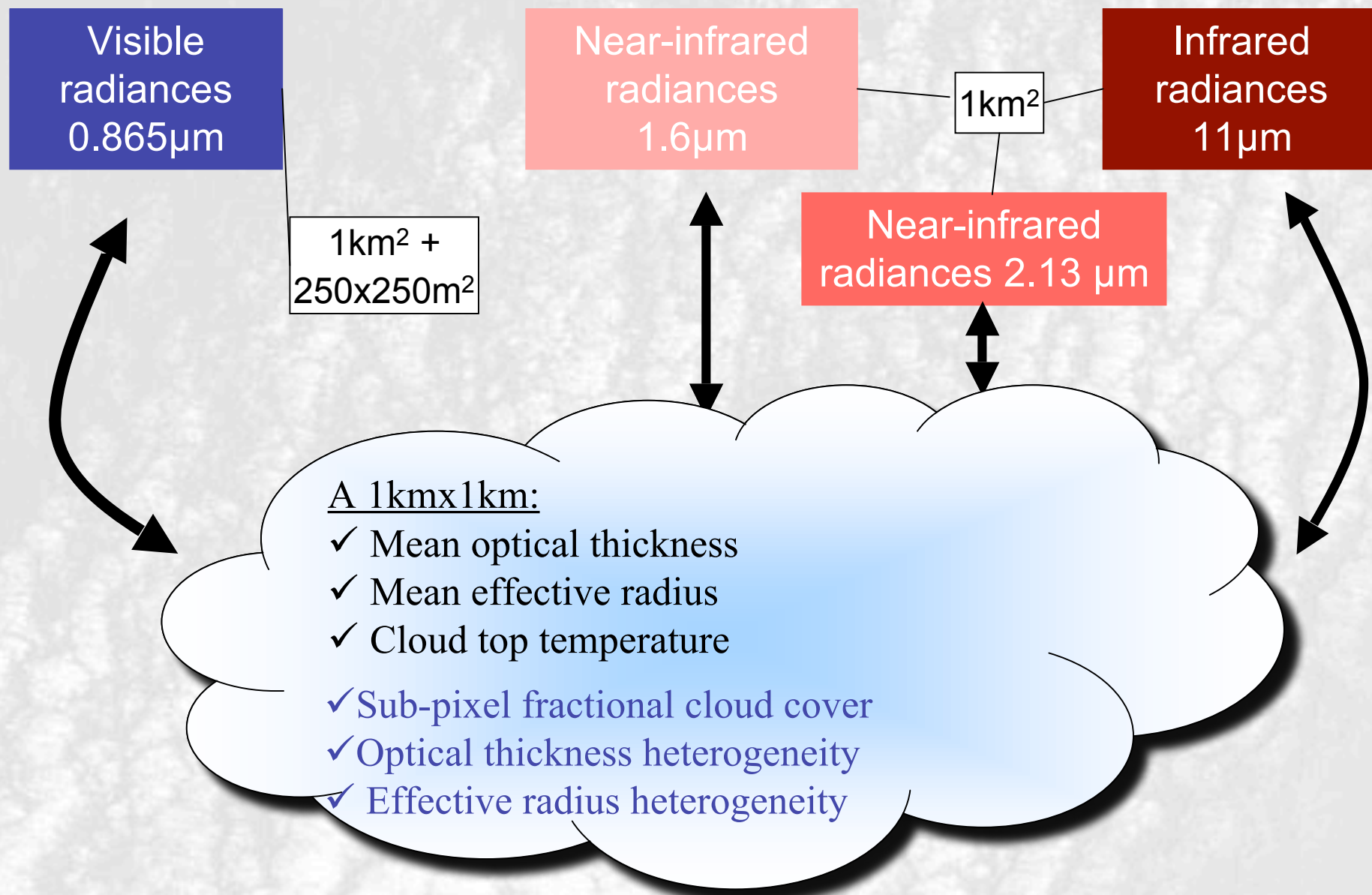
Multispectral information (MODIS, GLI)

Relation between infrared radiances and fractional cloud cover
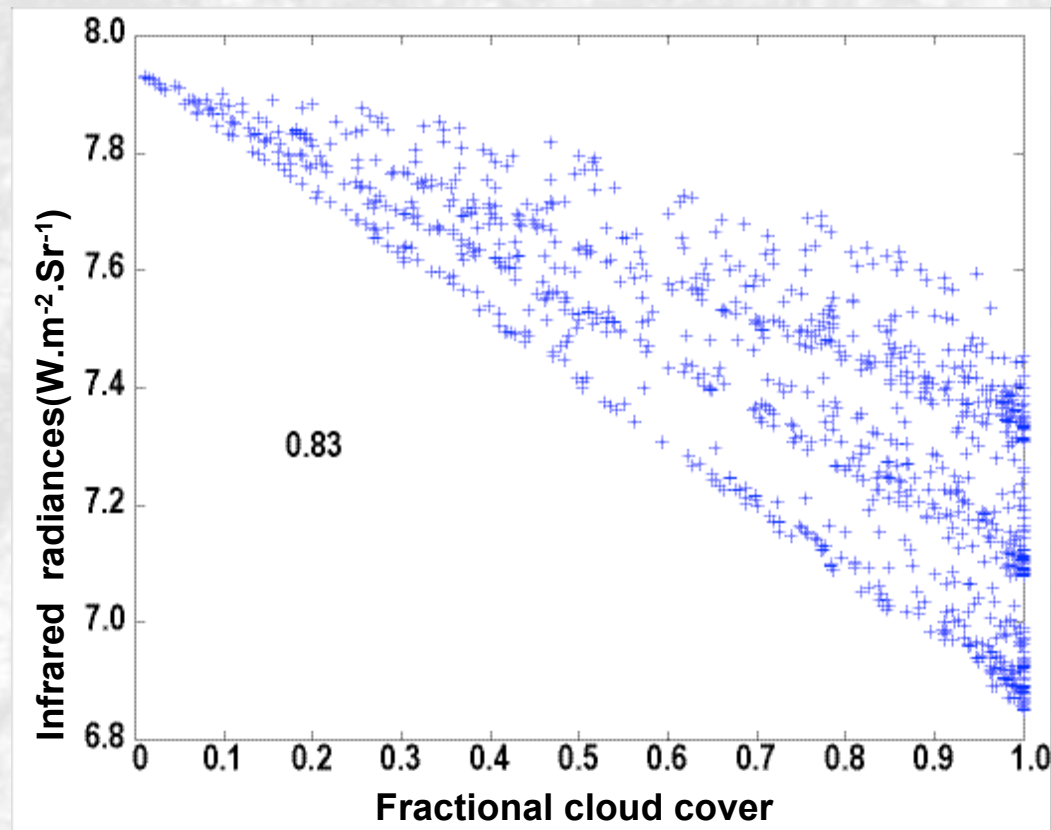
A tool: the neural networks

• Increase of data and parameters
⇒ Usual method (look-up table, cost function...) very difficult to use
⇒ Use of neural network *(Faure et al., JGR, 2001; Cornet et al., JGR, 2004)*

$$\vec{a}_k = f_k(W_k \vec{a}_{k-1} + \vec{b}_k)$$
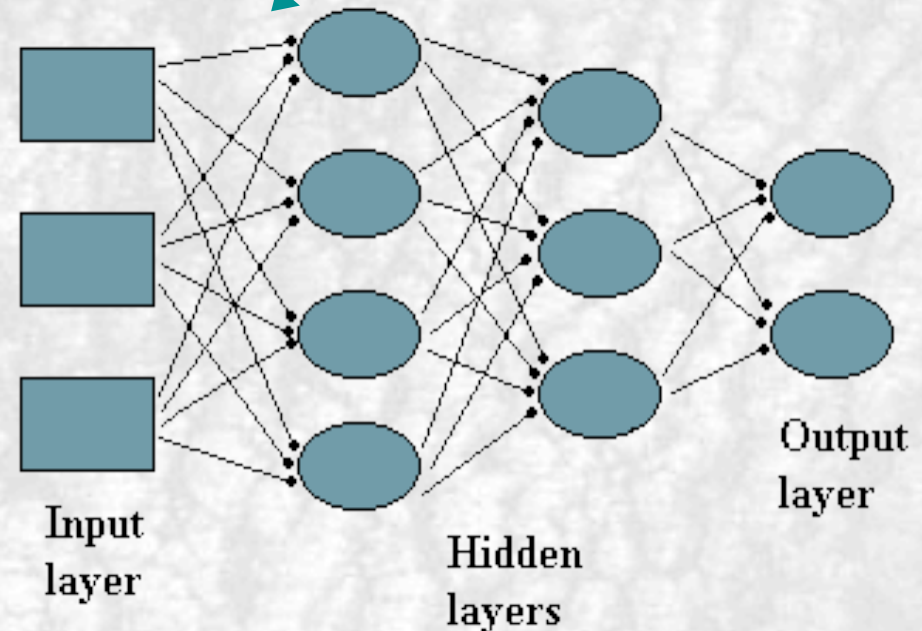
Need to adjust the weight and biases = training stage
⇒ need a database composed of associated input and output

Database building

**Cloud field:** bounded cascade cloud model

(128x128 elementary pixels of 50x50m^2)

- correlation between τ and Re fields

- cloud geometric depth varies as the square root of τ with a mean value of 300m

- cloud base: 1200 m (for all the solar wavelength)

Radiances simulation: SHDOM

- angular step of 2.5° for the solar and view zenithal angle 5° for the view azimuthal angle

- for thermal band: 3 surface temperatures (276, 280 and 284 K) 3 cloud base height (0.90, 1.20 and 1.50 km)

Database building

Cloud = Bounded cascade model
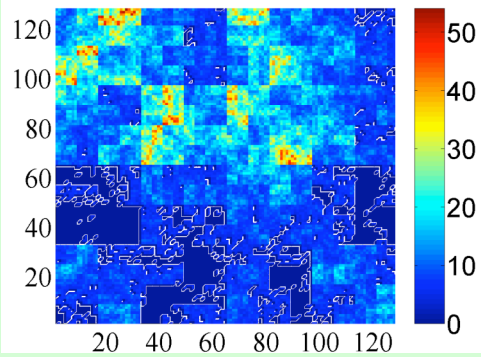
Elementary pixel: 50mx50m

Radiative transfer = SHDOM

+atmosphere, aerosol, surface

Selection of 20x20 pixels $\Rightarrow$ 1kmx1km

Average on 20x20 pixels $\Rightarrow$ 1kmx1km
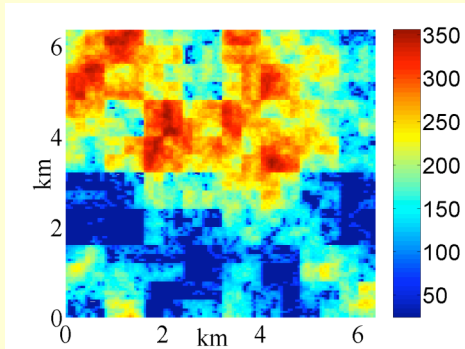
Average on 5x5 pixels $\Rightarrow$ 250mx250m

Optical thickness field at 1x1km

Cloud properties at 1kmx1km
- Mean optical thickness : τ
- Mean effective radius : *re*
- Optical thickness heterogeneity : σ_τ
- Effective radius heterogeneity : σ_{re}
- Fractional cloud cover: cf
- Cloud top temperature: T_{cl}

Radiances at 1kmx1km: 0.865, 1.6, 2.13, 11 μm

Visible radiances

+
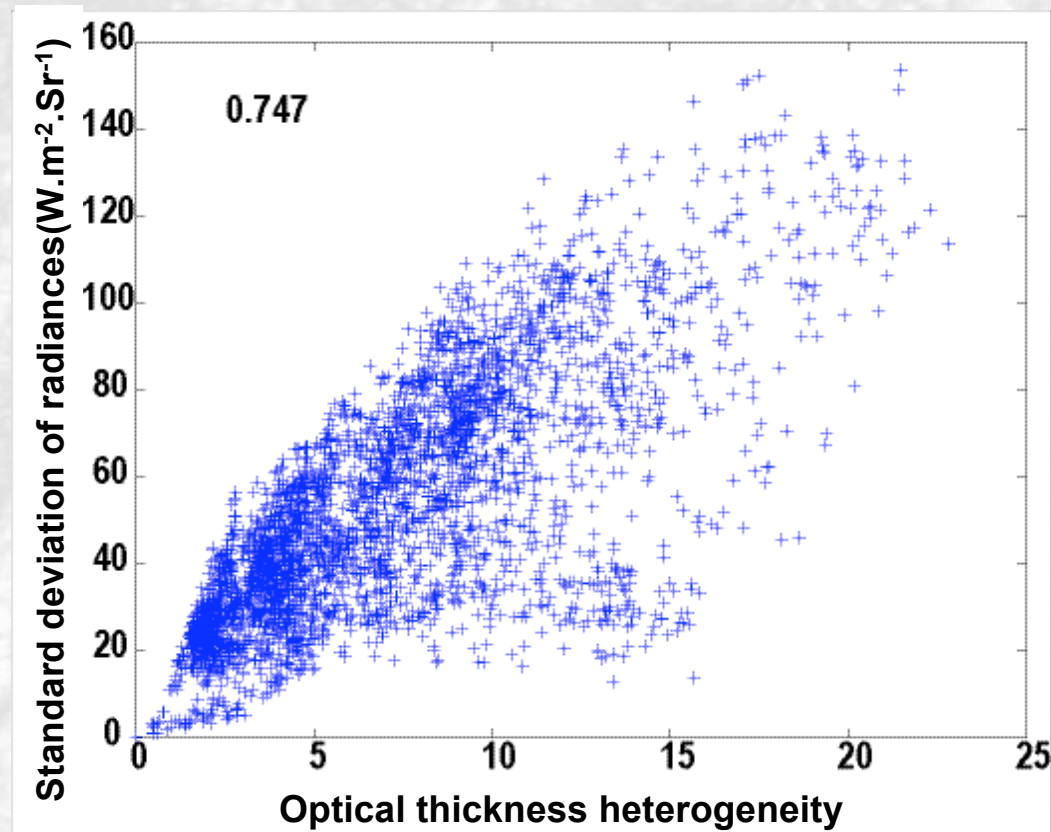
Standard deviation at 1kmx1km estimated from 250mx250m pixel
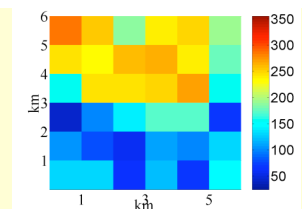
Use of multi-scale information

Relation between standard deviation of visible radiances and optical thickness heterogeneity

Training

Input vector (8 components):
1) Mean visible radiances (0.865μm)
2) Mean radiances at 1.6 μm
3) Mean radiances at 2.2 μm
4) Mean radiances at 11 μm
5) Standard deviation of visible radiances
6) Surface temperature
7) Zenithal angular distance
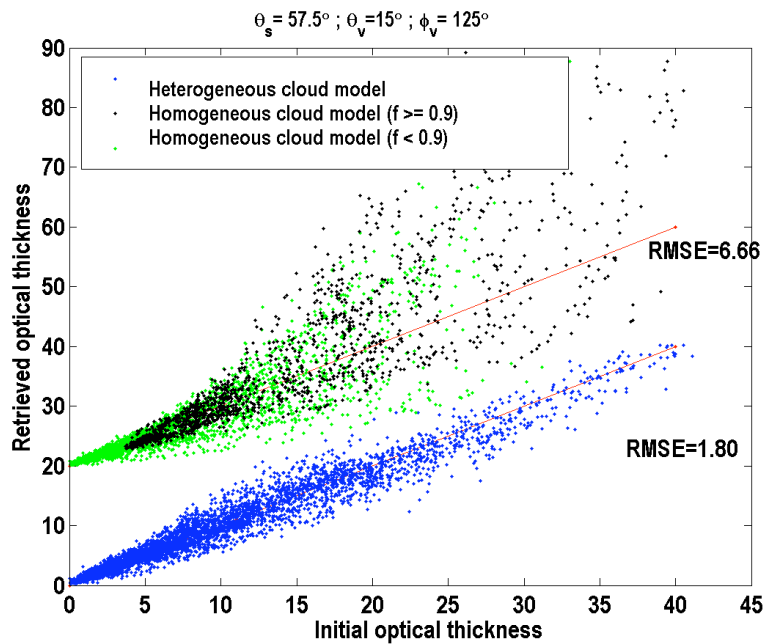8) Azimuthal angular distance
9) Solar zenithal angular distance

Training done with 20000 examples

2 hidden layers with 5 neurons

Back-propagation algorithm with Bayesian regularization

Comparison with the homogeneous assumption

Optical thickness

Effective radius
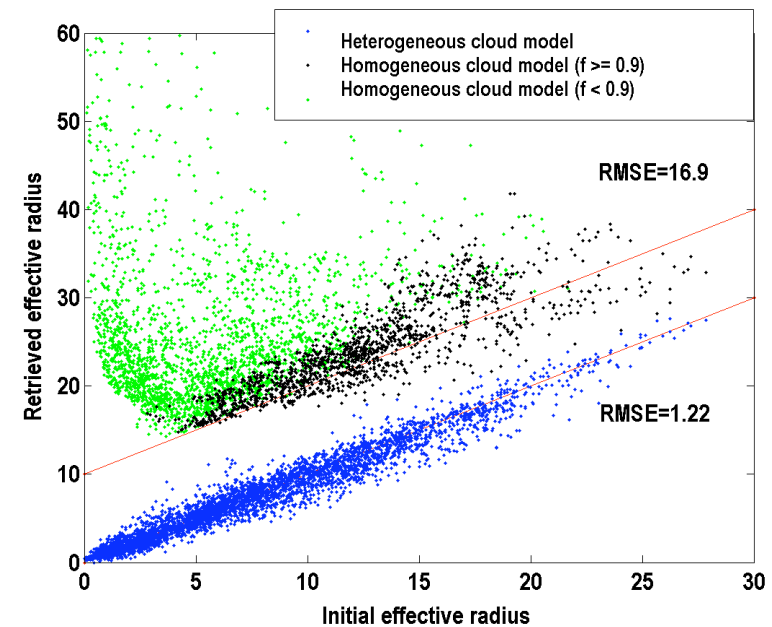
•Small Re: multiple solution + fractional cloud cover presence

Test with a different kind of cloud

Tests with two kinds of synthetic inhomogeneous and fractional clouds:

1) Bounded cascade clouds with different conditions than during training
   - Solar incidence: 57°
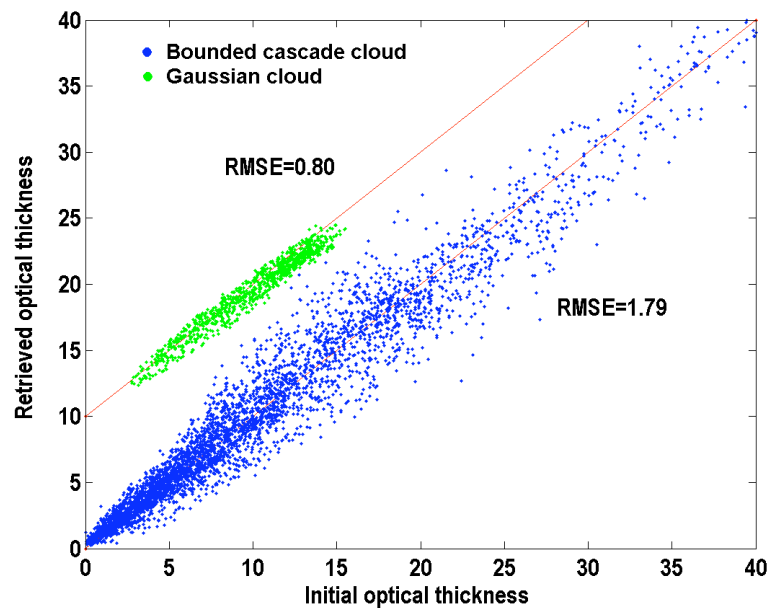   - Observation angles: (θ_v= 15°,φ_v= 125°)

2) Gaussian process clouds
   - Solar incidence: 58°
   - Observation angles:(θ_v= 15°,φ_v= 125°)
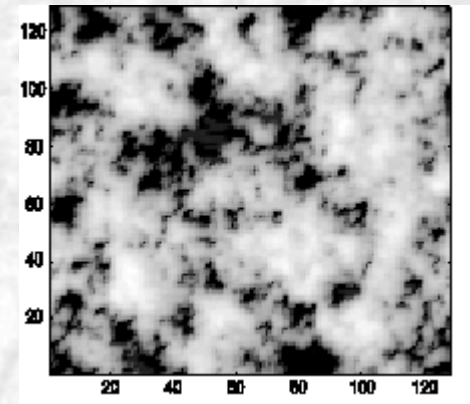
Test with synthetic data
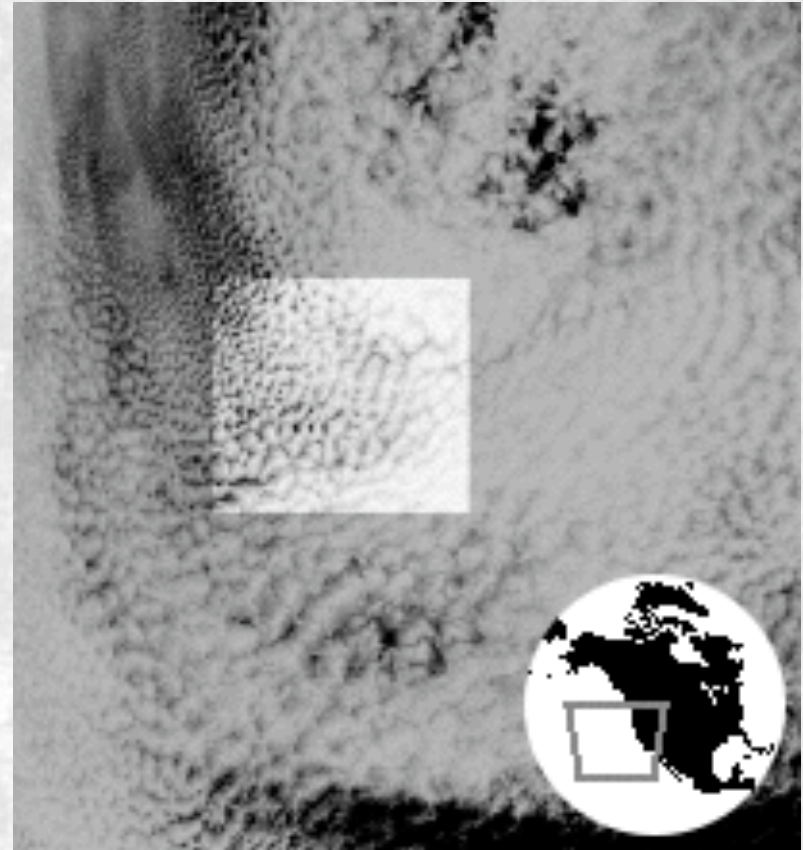
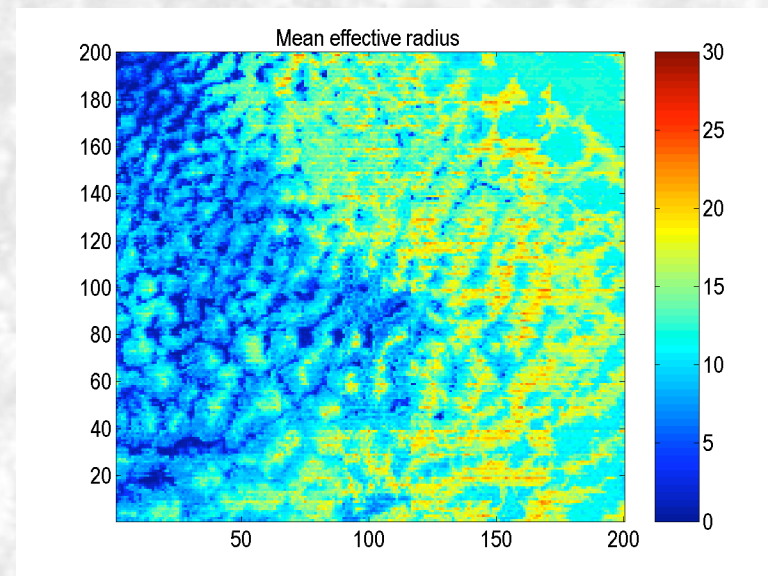## Mean optical thickness

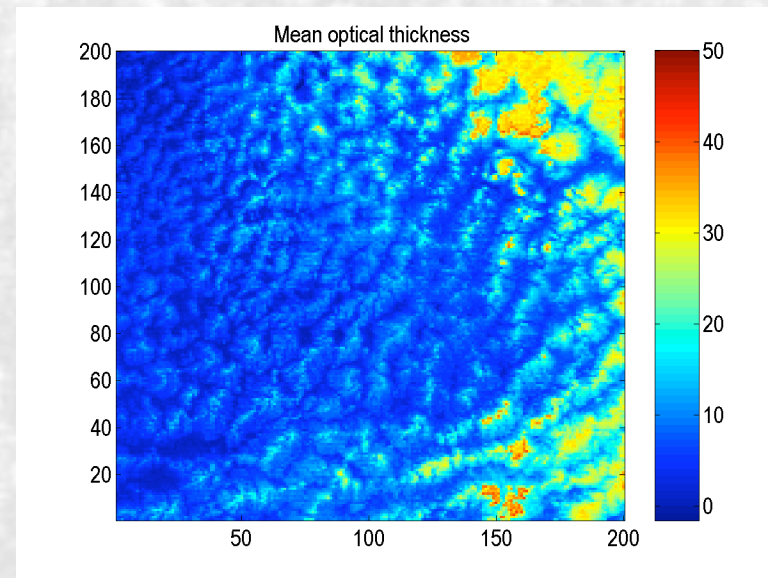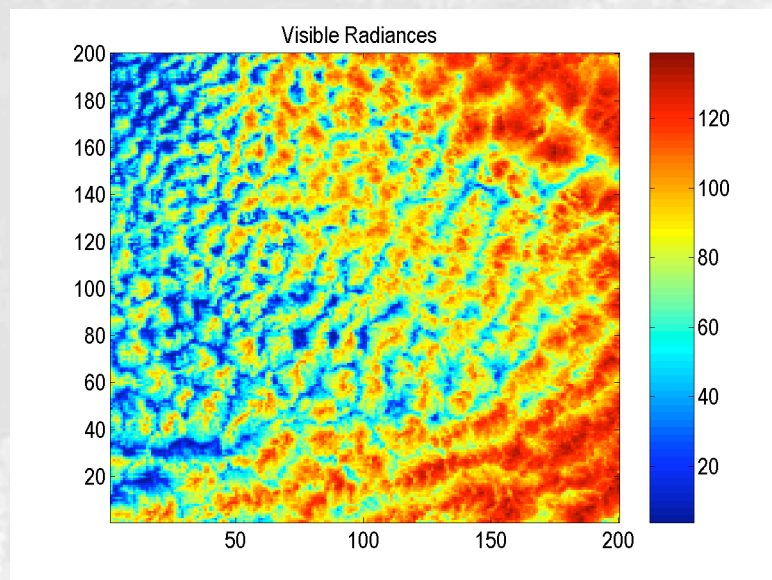## Mean effective radius
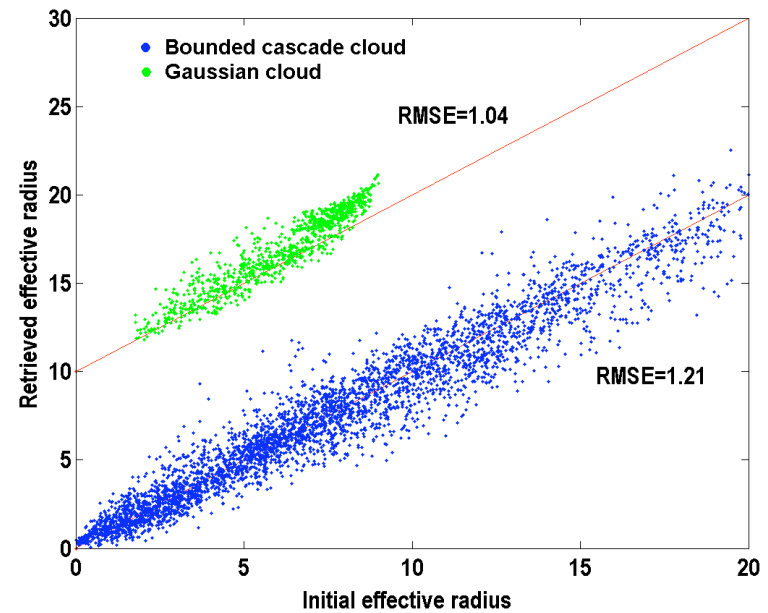
Test from MODIS data

Limited database ⟹selection of a cloudy scene:

• Stratocumulus clouds with fractional cloud cover

• oceanic surface: 5 m/s

• sun ~ 60º; θ_v~ 15º-35º; φ_v ~ 120º

9 February 2003 (West USA): 200x200km scene
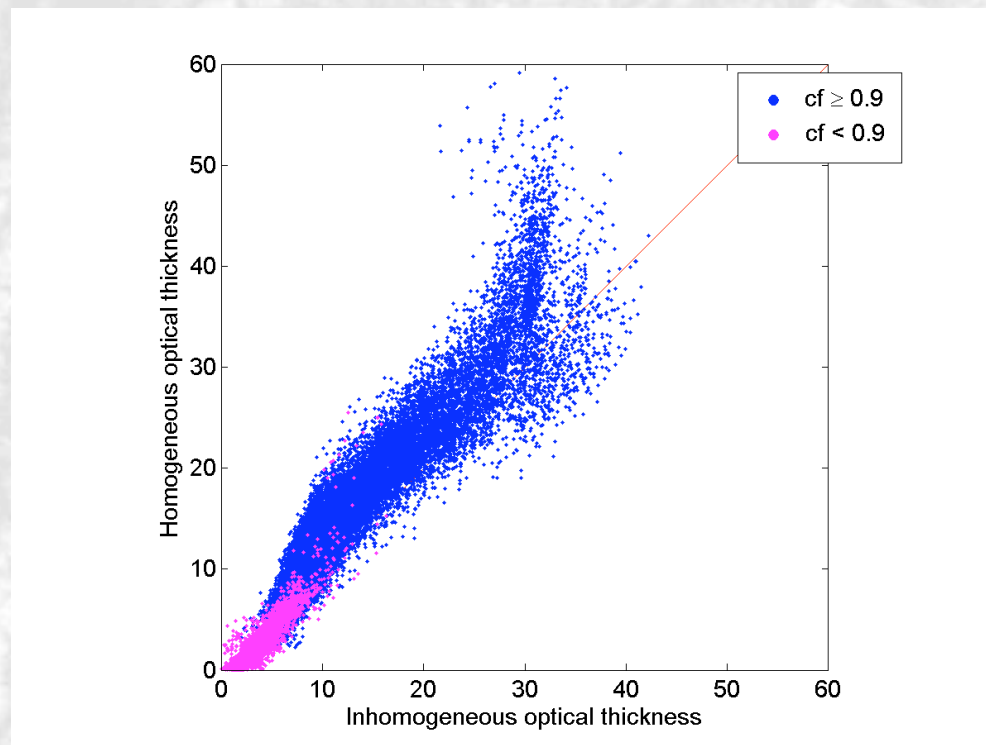

Cornet et al. GRL, 2005

Optical thickness and effective radius retrieval

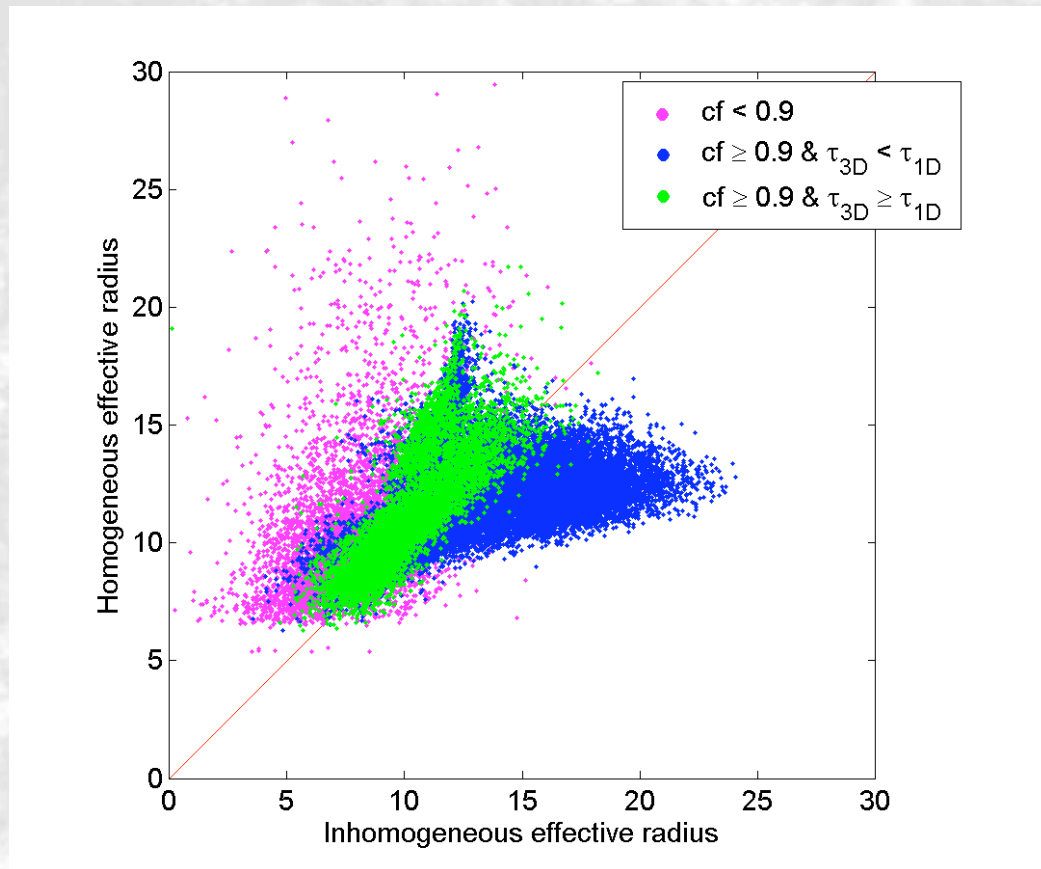# Optical thickness retrieval

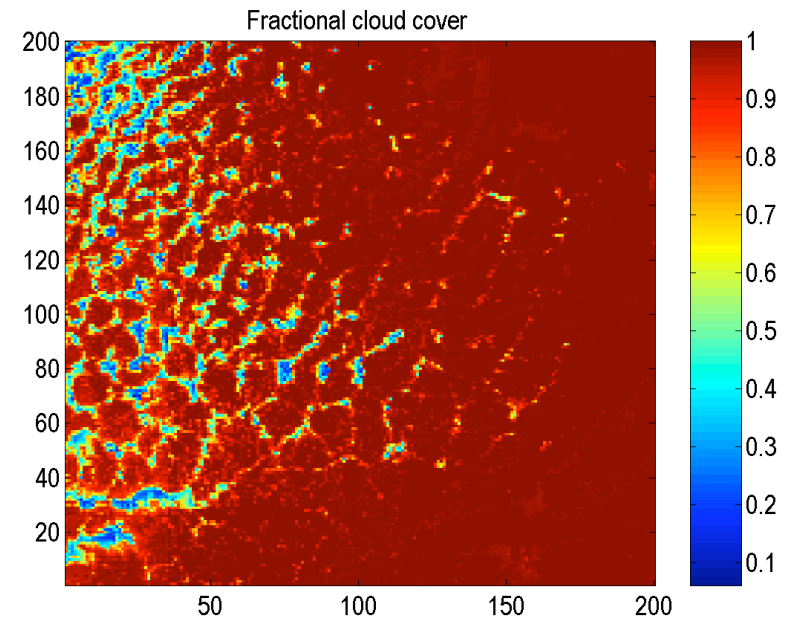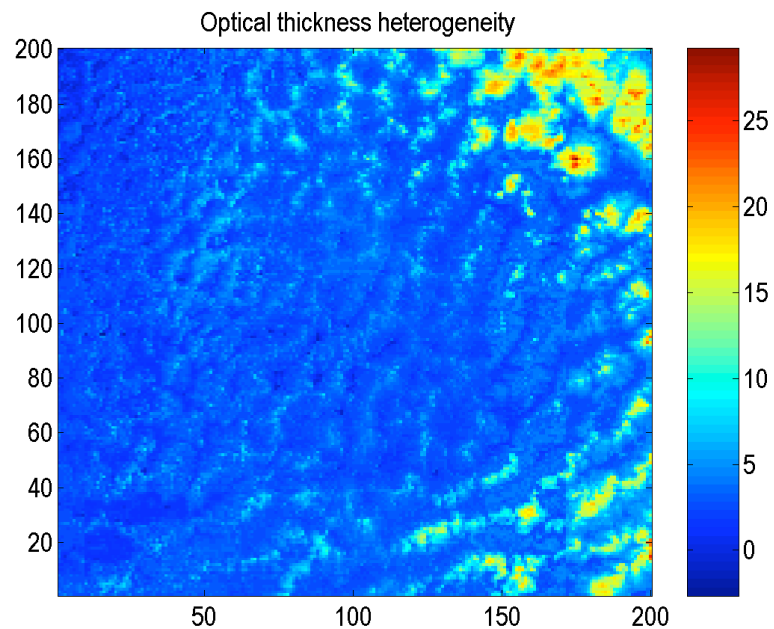## Comparison with MODIS products

Effective radius retrieval

Comparison with MODIS products

$\tau_{3D} < \tau_{1D} \Leftrightarrow$ **"brightness effects", Re$_{3D}$ > Re$_{1D}$**

$\tau_{3D} >= \tau_{1D} \Leftrightarrow$ **"shadowing effects", Re$_{3D}$ < Re$_{1D}$**

Optical thickness heterogeneity and fractional cloud cover retrieval

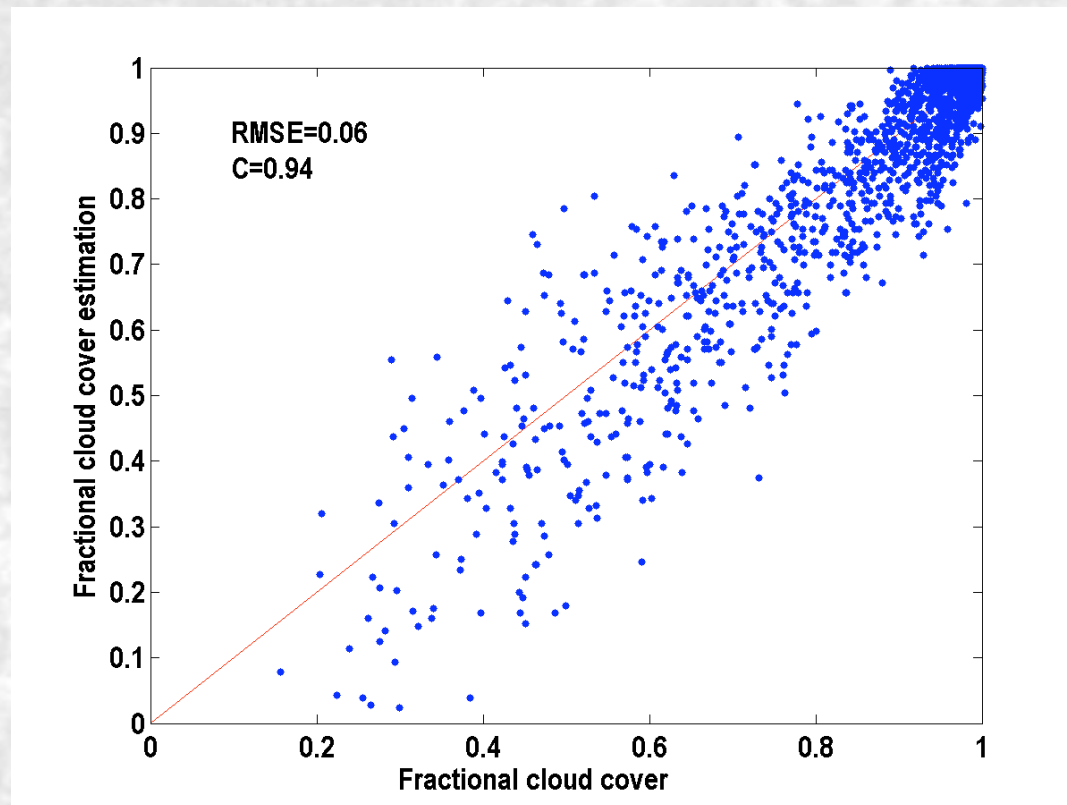Optical thickness heterogeneity

Fractional cloud cover
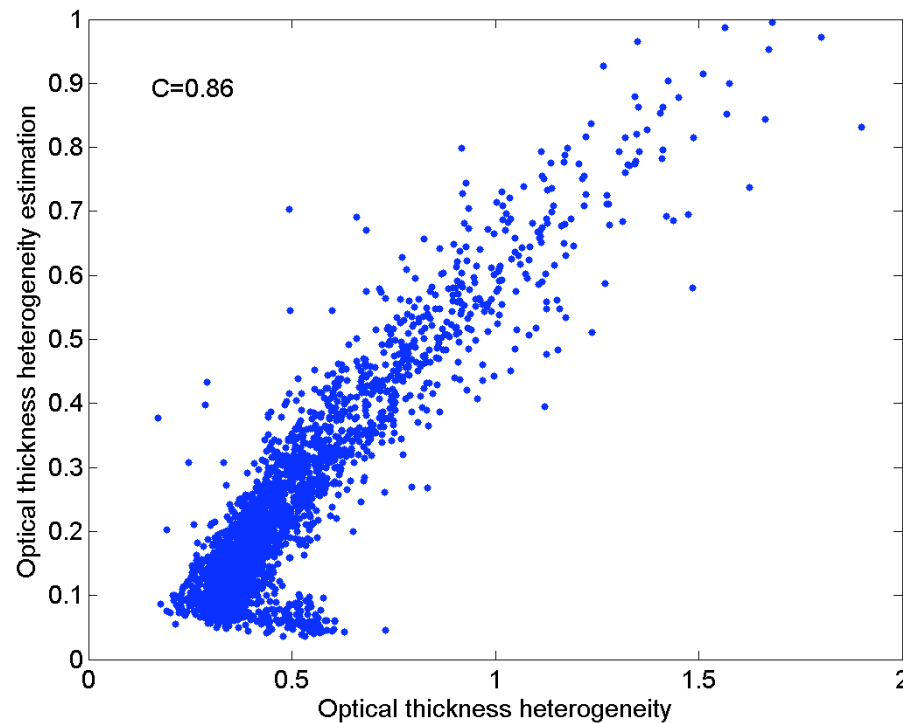
Fractional cloud cover retrieval

Comparison between:
- neural network retrieval at 4km
- estimation of fractional cloud cover at 4km from visible radiances at 250m (threshold: $[R_{min}+(R_{max}-R_{min})/5]$)
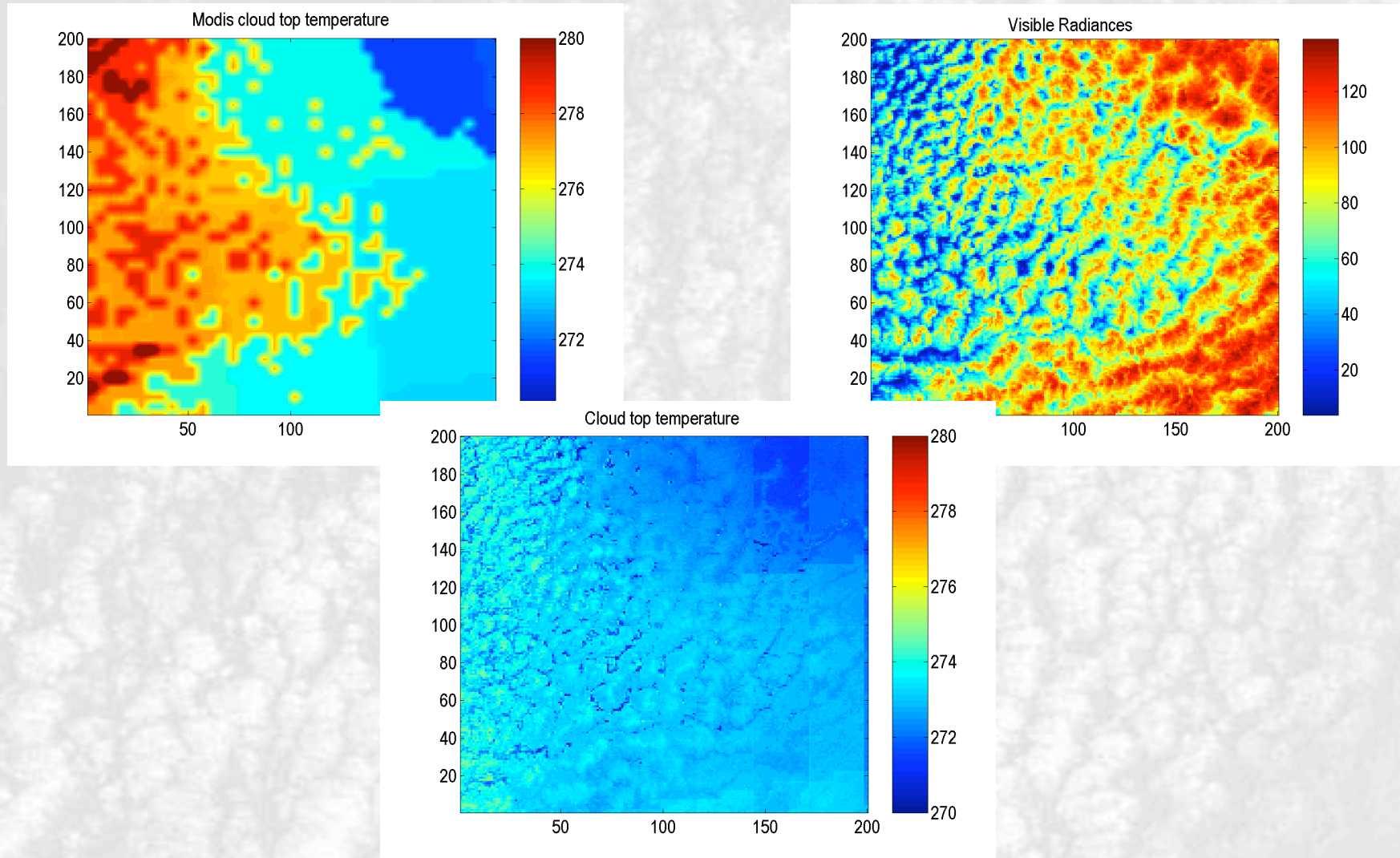
Optical thickness heterogeneity retrieval

Comparison between:
- neural network retrieval at 4km
- estimation at 4km with the standard deviation of visible radiance from 250m

Cloud top temperature retrieval

Comparison with MODIS products

Conclusion

- **Retrieval procedure for inhomogeneous and fractional clouds**:
    - ✓ Based on neural network techniques
    - ✓ Based on the use of multispectral and multiscale informatio

- Test on the retrieval procedure:
   - ✓ With a different synthetic cloud in different conditions
    - ✓ With MODIS data

$\Rightarrow$ Possibility to retrieve with a better accuracy: τ ; r_{eff} ; T_{cloud}

$\Rightarrow$ Possibility to retrieve new parameters: σ_{τ} ; σ_{reff} ; cf

- Possible improvements:
    - ✓ More extensive test to know better the limits
    - ✓ Increase the database representativity and use of more "realistic" cloud to train neural network.
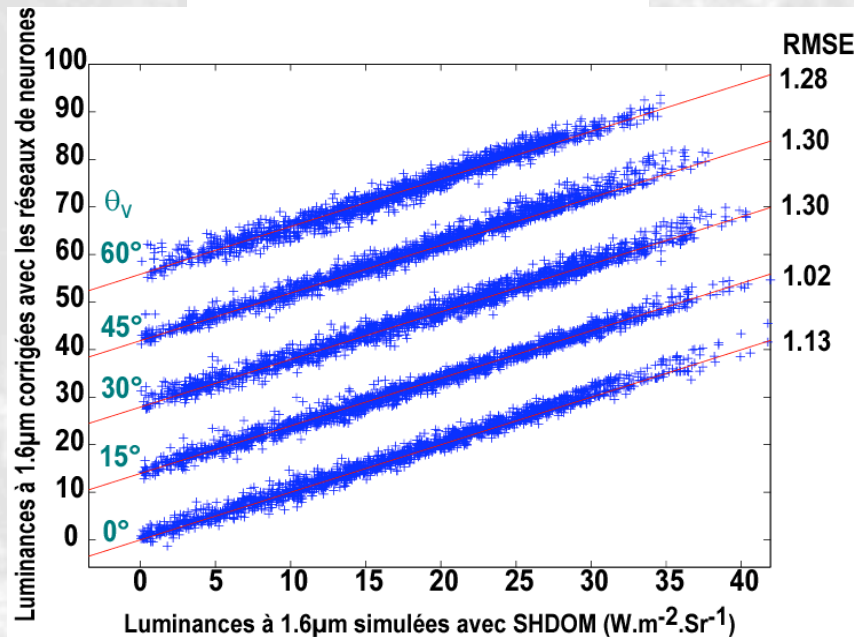
Retrieval above land
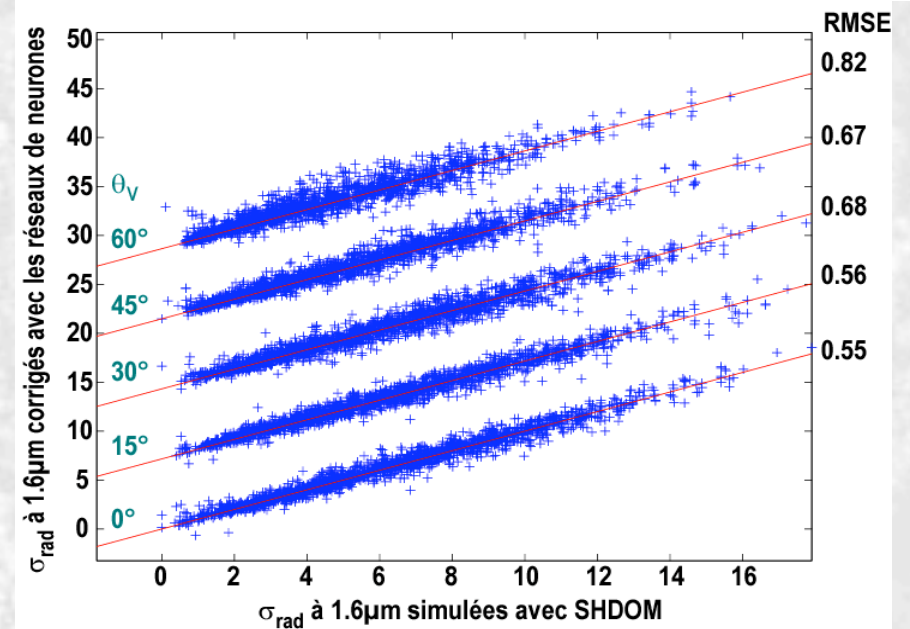
Possibility to remove ground albedo contribution
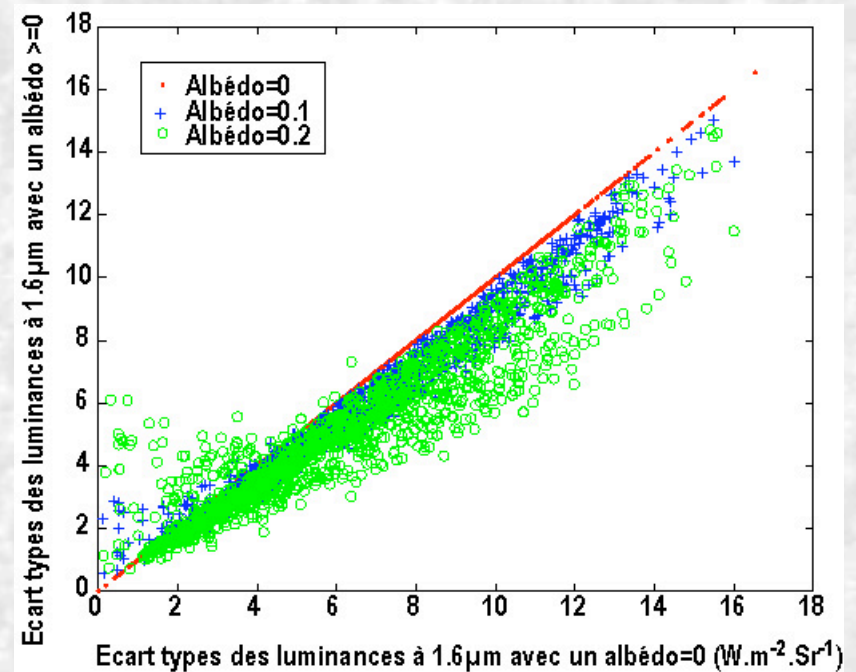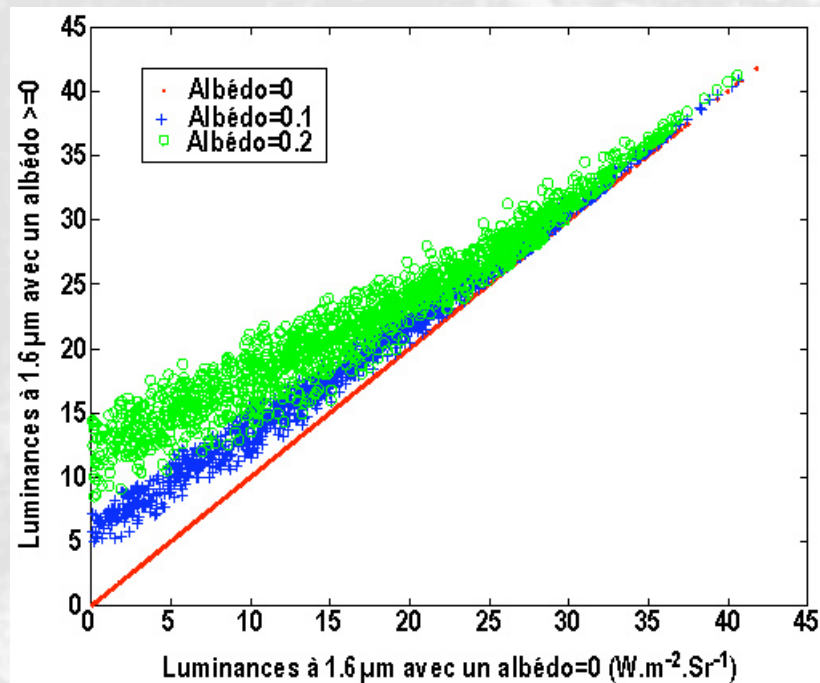
Retrieval above land

Solar incidence: 30°; azimuthal angle: 90°

Radiances at 1.6µm

Standard deviation of radiances at 1.6µm

Comparison with the homogeneous assumption